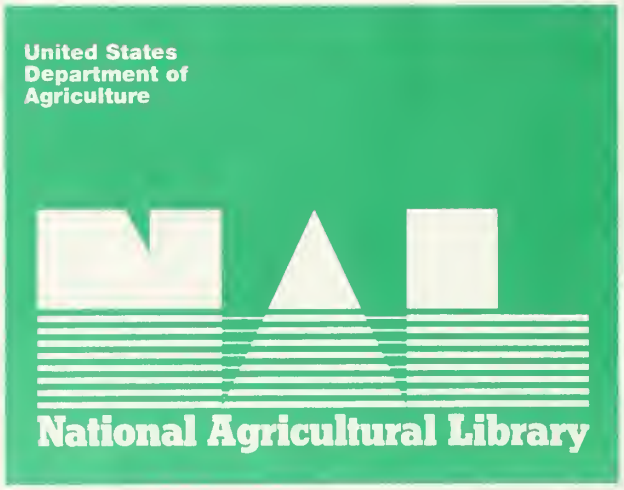
Healthy Forests for the Future

Research at the USDA Forest Service

Northeastern Forest Experiment Station's Center for Forest Health Research at Hamden, Connecticut



The USDA Forest Service's Northeastern Forest Experiment Station had its beginnings in 1923 with a research unit in Amherst, Massachusetts. For more information about the 75th anniversary celebration—to be held June 10, 1998, in Radnor, Pennsylvania—of the USDA Forest Service's Northeastern Forest Experiment Station, contact the station's External Communications Office by telephone at (610) 975-4112, by e-mail at dmcgee@hp1.nena.org, or by mail at 5 Radnor Corporate Center #200, Radnor, PA 19087. The station's World Wide Web homepage can be found at http://www.nena.org/NE_Home/

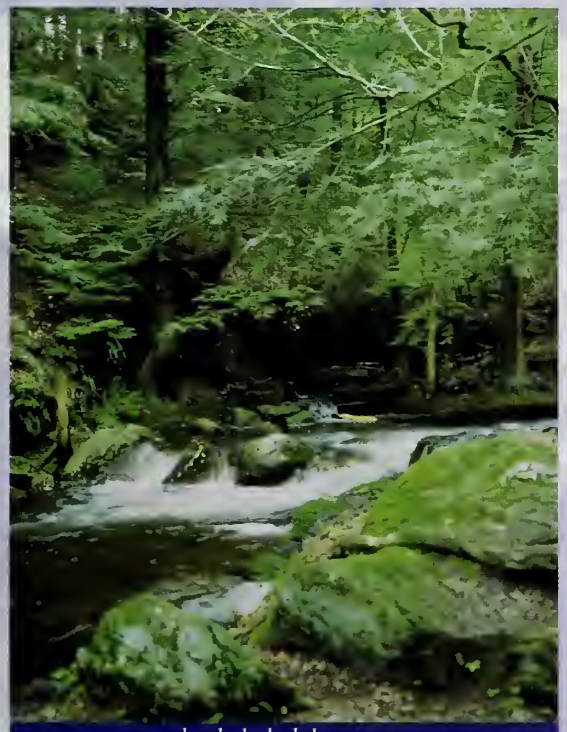
For more information about research and other programs at the USDA Forest Service, Northeastern Forest Experiment Station's Center for Forest Health Research at Hamden, Connecticut, contact Dr. Philip Wargo, director's representative, at (203) 230-4304; by e-mail at /s=p.wargo/ou1=s24l07a@mhs-fswa.attmail.com, or by mail at 51 Mill Pond Road, Hamden, CT 06514. The Center's World Wide Web homepage can be found at http://www.nena.org/Hamden/

Cover photo: canopy gap resulting from beech bark disease

Our Eastern Forests

To many of us, the trees and forests we see around us may seem like they've been here for a long time. We look at the hardwood forests of the East and think they are ancient. Yet we don't remember our history. Most of the eastern forests were first cleared to create fields for farming and for wood to build and heat houses and later to make charcoal for iron smelting. This began with the first European settlers, reoccurred during the Industrial Revolution, and continued as late as the early 20th century. As making a living as a farmer in the East, especially in stony New England and the mountains of the South, became more and more difficult, more and more farms were abandoned.

When farm fields are abandoned, the process of forest succession begins, and what were once fields become forests again.



hemlock-shaded streams

MOST OF WHAT WE NOW KNOW OF AS FOREST HERE IN THE EAST WAS NOT FOREST EVEN 70 YEARS AGO.

One hundred years ago, 75% of Vermont was "open land" and now 75% is forested. Many of the eastern national forests and national parks began as worn-out mountain farms that were purchased or taken over by the federal government. For example, the forests of Shenandoah National Park and the George Washington National Forest, with their towering yellow-poplars and oaks, were bare fields as late as 1920.

The Return of the Forests

Indeed, our forests are on an upswing—there is now as much forested land nationwide as there was in 1920 and virtually every state east of the Mississippi River has more forest land now than in 1900. But we know that **these new forests are not the same forests that were here when the first Europeans came.** There are several reasons for this. The first is the basic fact that forest ecosystems are dynamic and are constantly changing in response to selection pressures, successional forces and disturbance from disease, drought, fire, insects, and movements of earth, wind, and water. These disturbances maintain earlier successional species or set back succession to earlier stages. Indeed, the forests that greeted the European settlers may not be indicative of the earliest forests that existed here, for Native Americans manipulated the forests by cutting clearings and burning undergrowth. Disturbance continued as the European settlers began major forest removals soon after their arrival, and much of the eastern forests disappeared. Since early in this century, much of the land cleared for farming has been abandoned and the forests are beginning to grow back. However, many forests are still in their earlier successional stages and their age and species composition will continue to change.

But Are These New Forests Healthy?

There is a second reason that these new forests are different from earlier forests. Not just land clearing and timber harvest have taken their toll—**in the last two centuries many organisms** (both insects and

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gypsy moth caterpillar

beech scale crawler

beech bark fungus—nectria

disease-causing microorganisms) were inadvertently transported to our shores from Europe and Asia. Some of these exotic organisms have caused major changes in the health and composition of our forests, and thus have been termed pests. Some conspicuous examples include the fungi that cause chestnut blight, Dutch elm disease, and white pine blister rust; the fungi and scale that cause beech bark disease (see page 6); and the gypsy moth (see page 4) and the balsam and hemlock woolly adelgids (see page 2). These pests have essentially permanently changed the forests of the eastern United States or could do so in the future. The tree species that are affected by these exotic pests are abnormally threatened, and several (the American chestnut and elm) have almost disappeared in our lifetimes.

Native pests—saddled prominent and forest tent caterpillars, the two-lined chestnut borer, armillaria root fungi—also affect our forests when they occasionally reach outbreak conditions, sometimes from biological or physical disturbance, from environmental factors, or from management activities that weaken

hemlock woolly adelgid egg sacs

Eastern Hemlock

Hemlocks are late successional slow-growing, long-lived, and shade-tolerant trees that often occur in riparian areas. Groves of tall, old hemlock trees are an outstanding feature of eastern forests analogous to redwoods in the West. Although no longer highly prized by industry, hemlock ranks among the top four species in New England and New York in volume of saw timber harvested.

hemlock woolly adelgid (X 200)

Eastern hemlock occurs throughout New England, New York, Pennsylvania, and the Appalachian Mountains. Outlying populations extend from southern Quebec southward to Georgia and westward to Minnesota.

Hemlock is a critical component of the forest ecosystem. It provides floristic and structural diversity to forests as well as environmental stability and protection for watersheds. The dense canopy of hemlock produces distinct microclimate and soil conditions and several threatened and endangered species are associated with this unique niche.

Presently, an exotic pest—the hemlock woolly adelgid, an aphid-like insect that feeds on plant tissues—is causing an alarming deterioration of the health of eastern hemlocks.

Threats to Health

- Abiotic threats—drought and lightning
- Biotic threats—
  - *diseases*
    - annosus root disease
    - root and butt rot
    - stem decay
  - *herbivores*
  - *insect infestations*
    - hemlock woolly adelgid
    - needle scales
    - hemlock loopers
    - gypsy moth
    - spruce budworm
    - hemlock borer

Ongoing & Future Research Activities

- Assessing the biological impact of loss of hemlocks
- Determining the best management practices (BMP) for use in forested ecosystems threatened with loss of hemlock from the hemlock woolly adelgid
- Developing procedures to monitor the health and vulnerability of hemlock
- Establishing biological control agents for this adelgid
- Studying the impacts of hemlock woolly adelgid feeding on tree physiology and determining ways to increase tree resistance

dead and dying hemlocks

armillaria root disease fungus

trees. The impact of either exotic or native pests depends on the value of the affected resource and the management objectives for the disturbed areas.

Our forested ecosystems are complex and we are just beginning to understand many of the interrelationships of the biological, chemical, and physical components that determine the health and stability of forests. In every ecosystem, each of the successional stages has its own set of characteristics related to its plants, animals, soil, and climate. Human activities such as prescribed fire, arson, fire suppression, cutting timber, hunting and fishing, and recreation may also adversely affect ecosystems. The consequences of other human activities—global warming and pollution—have the potential to effect ecosystem change but research has not yet provided a clear understanding of their effects.

Much current forest health research is problem oriented. We need to expand our focus to see the whole picture—not just the pathogens and insects themselves, but their overall functions in forest ecosystem processes. Indeed, **we need to determine just what are the characteristics of forest health and how it is affected by disturbance from pathogens and insects.** This would allow us to interpret the role of disturbance from insects and disease in an ecosystem dynamics and management framework.

The Center for Forest Health Research at Hamden, Connecticut

The Center for Forest Health Research at Hamden, Connecticut, is part of the USDA Forest Service's Northeastern Forest Experiment Station, which is headquartered in Radnor, Pennsylvania. The Center, which is located in Hamden and Ansonia, Connecticut, has a long history of work on forest health problems. Federal forest tree insect and disease research in the Northeast began in Providence, Rhode Island, in 1912; Amherst, Massachusetts, in 1925; and New Haven, Connecticut, in 1929. The three units at these locations were consolidated in a laboratory in New Haven in 1932 near the Yale School of Forestry. When that laboratory burned in 1964, the Forest Service built a new laboratory in Hamden, just north of New Haven. The 13-acre facility at Ansonia was added in 1981.

The scientists working at this laboratory— entomologists, plant physiologists and pathologists, microbiologists, wildlife biologists, chemists—have achieved some outstanding research results. In the last several decades, interdisciplinary teams of researchers at the Center have

assessing tree pathogens

Center for Forest Health Research—Hamden, CT

- Developed a broad base of knowledge of gypsy moth ecology and the role of natural enemies on the moth's population dynamics.
- Contributed to the understanding of ecosystem diversity and its relationship to stand susceptibility to gypsy moth.
- Determined the causes, patterns of development, and organisms involved in decline diseases in maple, oak, beech, and red spruce trees.
- Clarified the roles of stress, opportunistic organisms, and soil chemistry changes in tree deterioration and death.

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preparing insect diet

- Developed practical systems for rearing gypsy moths for research and for sampling the insects in the forest.
- Learned how microbial control agents such as *Bacillus thuringiensis* (also know as Bt), viruses, and microsporidia can be better used to manage the gypsy moth.
- Developed, and registered with the EPA, two viral pesticides— Gypchek, which is specific for the gypsy moth, and Neochek-S, which is specific for the European pine sawfly—and isolated a new strain of Bt that has been subsequently commercialized by industry.

aerial application of microbial pesticide

- Developed methods for measuring the effectiveness of these new pesticides and for screening and evaluating promising new microbial products.

Center scientists have long been active in developing partnerships with researchers and research organizations, both here in North America and in Europe and Asia (see pages 5 and 10). With foreign scientists, they have conducted explorations in the native habitats of many of the exotic pests that were introduced into the United States and are seriously affecting our forests.

Scientists at the Center are organized into three units: Forest Insect Biology and Biocontrol, Forest Insect Pathology and Microbial Control, and Forest Disease Biology and Ecology.

Oak-Dominated Forests

oak stand defoliated by gypsy moths

Oak species are mid-successional species that dominate the forests of the eastern United States. The oak–hickory, oak–pine, and oak–gum–cypress types cover approximately 170 million acres and account for 42% of the total forest area and over one-third of all hardwood volume in the East. Almost half of growing oaks are in the more commercially valuable species group of select white oaks and select red oaks, which are prized as sources of wood for flooring and furniture. Oaks also are important sources of food (acorns) and habitat for many forms of wildlife, especially deer, bear, squirrels, turkey, and grouse. The oak genus *(Quercus)* is quite diverse—there are over 20 species east of the Mississippi River—and oaks occupy a wide range of sites. Thus a wide range of shrubs and herbaceous flora and fauna are associated with these various oak forest types. Because oaks dominate many ecosystems, there is often special concern when the health of oaks is in decline.

Threats to Health

- Abiotic threats—drought, frost, ice storms
- Biotic threats—
  - *diseases*
    - leaf anthracnoses
    - cankers
    - oak wilt
    - root diseases
    - oak decline
  - *insect infestations*
    - gypsy moth and other defoliators
    - two-lined chestnut borer
  - *herbivores*
    - deer

Future Research

- Understanding the role of disturbance on forest health and changes in current and historical oak ecosystems
- Increasing the resilience of oak ecosystems to disturbance by diseases and insects
- Relating habitats, soils, and land-use history to spatial patterns of oak decline
- Determining the consequences of establishment of Asian gypsy moth and other exotic and native pests on oak ecosystems and developing means to mitigate their effects
- Improving methods and products for controlling pest outbreaks
- Identifying effective biological control agents for gypsy moth and other insect threats

working with local scientists to collect gypsy moth pathogens in Romania

Forest Insect Biology and Biocontrol

Forest insects play vital roles in the health, productivity, and diversity of forest ecosystems. Although native forest insects can have both beneficial and negative effects on the health of forest ecosystems, accidental introduction of exotic species can result in significant negative impacts, primarily because the natural controls associated with these species are left behind in their native lands. The Forest Insect Biology and Biocontrol unit focuses its research on the biology and ecology of native insects of eastern forests and accidentally introduced insect pests and the biological control of these species using natural enemies imported from their native habitats.

The long-range goal of this unit's research is to understand the role that insects have in maintaining healthy forest ecosystems and to improve the sustainability of forest ecosystems by mitigating the effects of insects that impact forest health. Scientists trained in insect physiology, genetics, biochemistry, and ecology use a variety of tools to acquire an understanding of the fundamental biology and ecological relationships of forest insects and their natural enemies, and to develop improved technology for integrated management of forest insect pests.

Biological control research in this work unit has for many years focused on investigating the biology, behavior, and host interactions of established parasites, predators, and pathogens of the **gypsy moth**. This, together with extensive studies on the biology and population dynamics of the gypsy moth itself, forms a broad base of knowledge that is now being used to investigate and develop new approaches in biological control of the **Asian gypsy moth** and other newly introduced pests such as the **hemlock woolly adelgid.**

Unit scientists are taking the lead role in research on the Asian gypsy moth, which was recently introduced on both the East and West Coasts. This race of gypsy moth differs in several respects from the one introduced to the United States from Europe more than 100 years ago. Particular concerns are the more diverse diet of the caterpillars, the fact that female moths are capable of extended flight, and the potential for hybrid vigor. Project scientists are working with international regulatory agencies to reduce the likelihood that the Asian race of the gypsy moth will become established in North America, and to mitigate its impacts if it does become established. This requires the application of knowledge they have developed about the European race of gypsy moth, which is now well established in North America, and obtaining comparable information about the Asian race and potential Asian/North American hybrids. This work is extremely urgent and is complicated by the necessity of conducting much of the research in Eurasia or under quarantine conditions in the United States.

As international trade and commerce increases, it is likely that new insect species will be introduced. Some will be new pests of our forests. Before natural enemies from an exotic pest's native range can be introduced and established in a new ecosystem, researchers must consider the potential impact of the natural enemy on non-target native species, its effectiveness at low host-population densities, habitat preferences, host resistance, and interspecific competition. To carry out this work, unit scientists

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collecting predators of hemlock woolly adelgid

exotic insect research at the experimental quarantine facility

have established intensive collaborative working relations with other units at the Center and extensive cooperative working relations with the national and international scientific community specializing in biocontrol of forest insects. They have available a primary quarantine laboratory for receiving and studying exotic forest pests and their natural enemies. The USDA Forest Service Quarantine Laboratory, a field facility of the Center located in Ansonia, Connecticut, is certified for research on biological control of certain exotic insects. Unit scientists promote cooperative use of this facility by scientists from many organizations to accelerate development of biological control methods for managing forest insect pests.

Forest Insect Pathology and Microbial Control

Chemical sprays were long considered the best way to control insect pests that feed upon and damage urban or forest trees. However attitudes about how to protect our nation's forests have changed dramatically over the past 10 years because of the public's concern about human health and the environment. Chemical pesticides have been replaced largely by microbial pesticides such as *Bacillus thuringiensis* (Bt), while industry is pursuing development of more specific viral pesticides such as Gypchek, the natural gypsy moth viral product, and other biorational pest control products such as pheromones. Additionally, there is national interest in using classical biological control agents such as parasites and pathogens to manage pest populations that threaten the health of America's trees and forests. This new emphasis is welcomed by scientists in the Center, who have quietly but effectively been pursuing these avenues of research for many years and represent the only unit of its kind in the Forest Service. Unit scientists are trained in insect pathology, microbiology, and entomology and are experienced in conducting both laboratory bioassays and large area replicated field experiments.

The team conducts research to better understand the effects that natural disease agents such as viruses, bacteria, fungi, and microsporidia have on pest

beech trees affected by beech bark disease

Northern Hardwoods—Beech & Maple

Sugar maple and beech are important late successional dominant species in northern hardwood forests. These species account for about 20% of the volume of growing stock in the northeastern and north-central United States.

Sugar maple occurs throughout the East except for the southern Piedmont and Coastal Plain and is highly prized for its wood—especially in its birds-eye or curly form—for furniture, paneling, flooring, etc. The species also provides the raw material for the production of maple syrup in the northeastern United States and has spectacular fall foliage coloration. Ecologically, sugar maple is considered a soil builder because of the fairly high levels of calcium in its leaves. Seedlings and saplings are very shade tolerant and consequently sugar maple is able to dominate many sites.

American beech occurs over a wider geographic range than sugar maple because of its tolerance of a wide range of soil and moisture conditions. In the past, beech has been considered a "weed tree" but now is more valued as export markets for beech flooring increase. It is also being recognized for its value as wildlife habitat and the most important food producer (beechnuts) for bear, deer, grouse, turkey, and several smaller mammals and birds in the northern forest. The fecundity of bears is strongly dependent on the availability of beechnuts.

Threats to Health

- Abiotic threats—frost, global warming, waterlogging, drought
- Biotic threats—
  - *diseases*
    - beech bark disease
    - maple decline
    - sapstreak disease (maple)
    - armillaria root disease (maple & beech)
    - eutypella and annual canker (maple)
  - *insects*
    - scale (beech)
    - borer (maple)
    - pear thrips (maple)

Future Work & Direction

- Determining the mode of inheritance of resistance to beech scale and develop methods to propagate resistant beech
- Evaluating past management practices on development of beech bark disease and sugar maple decline
- Determining the relationship of habitats and soils with susceptibility and vulnerability of stands to disturbances by beech bark disease and maple decline
- Developing new methods for evaluating fine root vitality (health) and its relationship with forest health

insect populations and to develop strategies for enhancing their effectiveness in mitigating damage by pests. By knowing the details of how disease agents are transmitted among insect populations and what environmental factors affect their multiplication and spread, scientists will be able to predict the onset of natural disease outbreaks and thereby defer the use of pesticides where they will not be needed.

Through the efforts of project scientists, Gypchek, the gypsy moth virus product, was registered by the EPA in 1978, and Neochek, an effective virus of the European pine sawfly, was registered in 1983. When exotic insects such as the Asian gypsy moth are introduced into this country, unit scientists must quickly evaluate the efficacy of environmentally safe microbial products such as Gypchek and Bt before they can be used in eradication programs such as those recently conducted in British Columbia and North Carolina.

Efforts continue in several areas to improve Gypchek: scientists are working with industry to improve the formulation and efficacy of the virus and thereby accelerate its commercialization and availability; researchers are cooperating with the Northeastern Station's biotechnology unit at Delaware, OH, to identify more virulent natural strains of the virus and evaluate genetically engineered strains; and Center scientists are cooperating with the National Center of Forest Health Management to improve the performance of the virus and other microbial products.

virus-killed gypsy moth caterpillars

Project scientists have had a major impact on the public's acceptance and use of the bacterial pesticide Bt for management of the gypsy moth, spruce budworm, and other forest defoliators. Research is being conducted cooperatively with industry to evaluate and select Bt strains and commercial formulations that possess enhanced potency against these species. Another factor in the acceptance of microbial pesticides such as Bt has been the major improvement in technology for aerial application. Center scientists, in collaboration with specialists from universities, other Federal agencies, and the Forest Pest Management Institute in Sault Ste. Marie, Ontario, developed protocols for the aerial application of Bt that have dramatically improved its performance against forest defoliators. The Ansonia field facility is integral to the unit's research program and is a focus for activities such as the production and evaluation of microbial pesticides and their simulated application.

Widespread use of Bt has caused concern about its impact on other species of Lepidoptera, that is, moths and butterflies. Consequently, unit scientists are conducting laboratory and field assessments of the effects of Bt on native Lepidoptera species of oak forests.

Scientists at the Center also are examining classical biological controls that could better manage the gypsy moth and other forest defoliators while minimizing disruption to forest biodiversity. Several species of microsporidia (bacterial pathogens) that are native to the gypsy moth in Eurasia but not North America are being evaluated for introduction and establishment against the gypsy moth. These pathogens, which cause chronic diseases and are important mortality factors in Eurasian gypsy moth populations, could significantly increase the natural control of the gypsy moth in the United States.

In addition, Center scientists are collaborating with scientists in Central and Eastern Europe to identify additional pathogens of defoliator species and evaluate their potential for introduction to North America.

Forest Disease Biology and Ecology

Nowhere are the complicated dynamics of forest health and forest ecological processes more evident than in the research underway on the disturbance to

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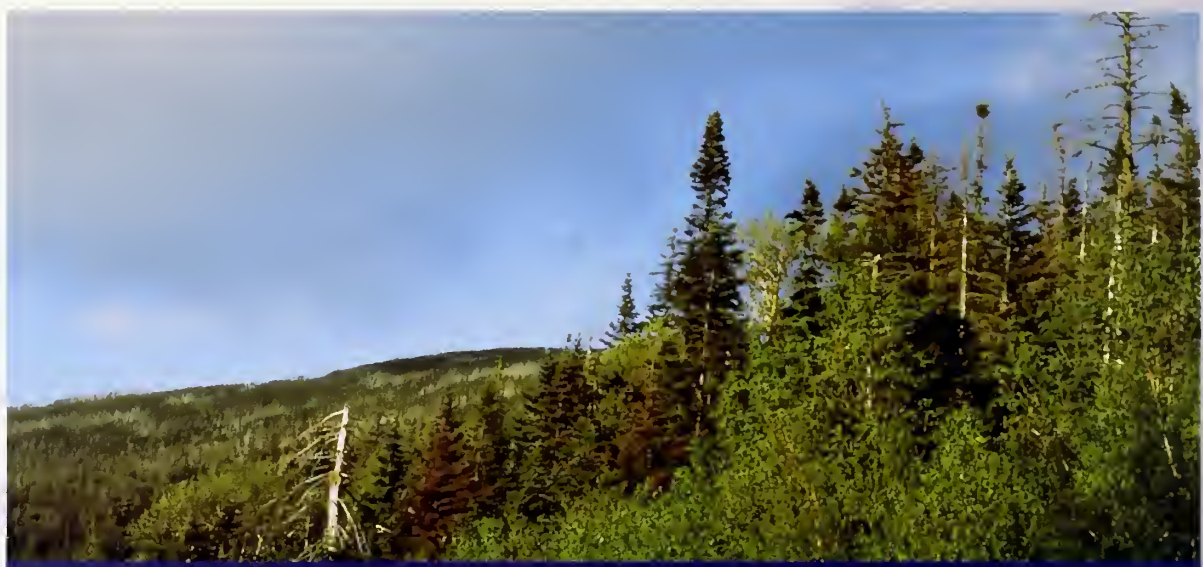
inoculating sugar maple with sapstreak disease fungus

forests caused by stress agents and their interactions with pathogens. Diseases can occur when trees weakened by such environmental stresses as insect defoliation, extremes of temperature and moisture, air pollutants, and attacks by sucking insects are unable to defend themselves and are invaded and often killed or rendered defective by opportunistic organisms.

Researchers in this group, located at Hamden and Durham, New Hampshire, have expertise in plant pathology, plant ecology, plant physiology, biochemistry, and soil science. They investigate the causes, patterns of development, and characteristics of these stress-triggered tree diseases, the ecology of the organisms involved in tree damage and mortality, and the influence of these disturbances on ecosystem attributes, processes, and their relationship to forest health. Over the years, their research focus has included ash dieback (drought triggered), beech bark



spruce decline in the Adirondack Mountains of New York

Facilities

Laboratory facilities for the Northeastern Center for Forest Health Research (located in Hamden and Ansonia, Connecticut) include

- **A state-of-the-art insect-rearing facility for colonizing forest insects and their natural enemies for research purposes.**
- **A 3,100-square-foot certified primary quarantine laboratory for confinement, colonization, and research on exotic insects.**

experimental spray tower at Ansonia

- Fully equipped laboratories for growth and maintenance of bacterial, fungal, and viral pathogens of forest insects and trees.
- Environmentally controlled chambers for bioassay of microbial pesticides against forest pests and for investigating roles of abiotic and biotic factors in maintaining forest health.
- Image analyzer systems for color analysis of macro subjects, and for evaluating foliar deposits of microbial pesticides.
- Viral pesticide production facility for the manufacture of microbial pesticides and experimental microbial products.
- An ultraviolet (UV) light detection, monitoring, and emission system to study the effects of UV on microbial pesticides.
- A field complex that includes a greenhouse, a spray tower for evaluating microbial pesticides, and sophisticated equipment for formulating and testing microbial pesticides.
- Chemical analysis laboratories complete with UV and visible light spectrophotometers and gas and liquid chromatographs.
- Histology laboratories equipped for light microscopy and scanning and transmission electron microscopy.
- Laboratories equipped for research on molecular population genetics of insects, plants, and microbes in forest ecosystems.
- Computers (minicomputer, Macs, and PCs) for state-of-the-art data analysis, word processing, world-wide communications, and graphics.
- Complete photography and darkroom facilities.
- Living quarters for visiting scientists and temporary staff.

The permanent staff at the Center numbers about 40, including scientists, other professionals and technicians, and support personnel. At various times, temporary/seasonal staff and visiting foreign scientists swell the ranks.

disease (initiated by a scale insect), decline and mortality of oak and sugar maple decline (initiated by insect and frost defoliation and drought), sapstreak disease of sugar maple (physical disturbance related), and red spruce decline (hypothesized to be related to atmospheric deposition and other environmental stresses). Researchers have identified the organisms involved in decline diseases, elucidated the effects of stress on host tree physiology and chemistry, and determined the host–organism interactions resulting in decline. Related work has focused on how trees defend themselves and wall off invading organisms, how to measure tree vitality both physically and biochemically, and how to measure stress in mature trees.

This research team seeks to understand how the spatial distribution of stress-triggered diseases is related to plant species associations and how gaps created by these diseases spread within the forest. A major research focus will determine the mechanisms by which atmospheric deposition affects tree and forest health. Understanding these relationships will enable scientists to determine what forests or portions of forests are susceptible and vulnerable to disease, and develop methods and procedures to measure, predict, and mitigate disease before or when it occurs. Research will determine why some trees under stress are susceptible to opportunist pathogens and vulnerable to their effects, while other similarly stressed trees are not, and if these resistant traits can be perpetuated both spatially and temporally in the current and developing forest.

They seek to understand the role of opportunistic pathogens that operate as ecosystem "roguers," ridding ecosystems of under-productive trees and allowing new, vigorous trees to replace them and to determine if these organisms can be used as indicators and predictors of changes in forest health. Other studies will determine the distribution and role of opportunistic fungi in the forest and landscape and evaluate how competitive fungi affect their ecology and distribution. The role of decay fungi in woody debris decomposition on the forest floor and nutrient conservation and cycling in forest stands will also be investigated.

In cooperation with other Forest Service and university scientists, the unit seeks to identify the stressors and opportunistic organisms that will cause disturbance to the forests, to measure and characterize forest habitats where these interactions will cause problems, and to develop ecologically sound guidelines for managing the diseases they cause. Another major focus of this cooperative research is the clarification of the effects of environmental stresses and stand management practices on the vitality of fine roots and the relationship of root vitality to the health of trees, stands, and forests.

The group's research encompasses both field studies to observe and identify the ecological relationships of stress, tree, and interacting organisms, and laboratory studies under controlled conditions to clarify the genetic, physiological, pathological, and biochemical bases for the observed relationships. Molecular genetics and other biotechnological methods and techniques are among the laboratory research methods used.

Major goals of the group's research, closely tied to ecosystem management, are to develop an understanding of the interplay between ecological processes and the onset and development of stress-induced diseases, clarify the relationship of disturbance caused by these diseases to forest health and ecosystem integrity and sustainability of the production of a variety of goods, services, and amenities from these forested ecosystems, and create guidelines for managing these diseases.

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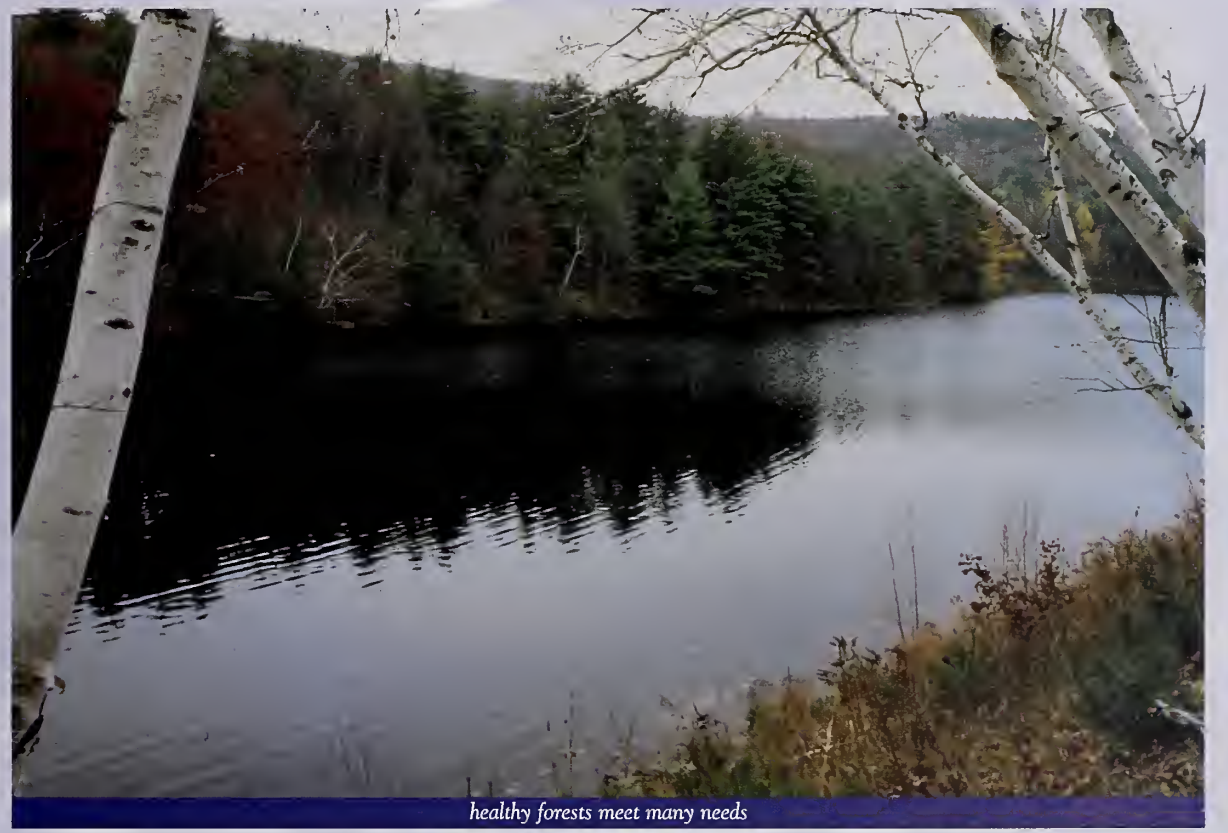

healthy forests meet many needs

Future Research at the Center for Forest Health Research at Hamden, Connecticut

Research in the Forest Service is now being directed at the broader issues of understanding forest health, managing ecosystems, and maintaining biodiversity. Scientists at the Center are responding to these new challenges by developing more holistic research approaches. Their work will be focused not so much on specific insect and disease problems as on the role of insects, microbials, and fungi in maintaining healthy forests. These organisms will be seen and studied not just as damaging pests but as functional parts of ecosystems. Center scientists will develop the biological information to meet the demands of effective ecosystem management.

The Center will continue to be involved in traditional long-term planned research, but it will also be a focal point for ad hoc teams for problem solving. This will involve collaborating with other parts of the Forest Service—the National Forest System, (which administers the national forests) and State and Private Forestry (which serves local and state governments and non-industrial private landowners)—as well as other groups of scientists in the

forest health issues require landscape-level approaches

Organizational Partnerships

The ability to network and establish viable partnerships is critical to every organization. At the Center for Forest Health Research at Hamden, Connecticut, we have an extensive list of cooperators:

working with state cooperators in Maine

- **Federal Agencies.** Because of our continued leadership role in gypsy moth research, we have close working relationships with other agencies in the United States Department of Agriculture such as the USDA's Agriculture Research Service (ARS), Animal and Plant Health Inspection Service (APHIS), and Cooperative State Research, Education, and Extension Service (CSREES). In addition, we provide technology and support to the U.S. Department of the Interior's National Park Service, Fish and Wildlife Service, and Geological Survey, as well as to the U.S. Environmental Protection Agency.
- **State Departments of Agriculture, and Natural Resources, Agriculture Experiment Stations, and State and Private Universities.** Joint studies, often facilitated by formal cooperative agreements, are conducted with scientists from various state agricultural experiment stations and state and private universities. Additionally, Center scientists provide technical expertise and assistance to scientists and managers at state departments of agriculture and environmental resources and, with their concurrence, conduct research on state and private lands within their jurisdiction.
- **Industry.** Collaboration with industry is encouraged and is mutually beneficial. Scientists work with industry to develop environmentally safe microbial pesticides by evaluating new strains and improved formulations, and by using new technologies for more precise application of these products to the forest. In addition, scientists work with exporters and importers to identify potential exotic pests and pathways and methods of introduction in order to assess risks and work to eliminate problems.
- **International Organizations.** Scientists at the Center think globally and develop partnerships with international organizations and scientists to address mutual problems related to forest health and ecosystem management. They have established a network for the exchange of scientific knowledge through participation in international conferences and symposia and scientific exchange programs, and by hosting extended visits by foreign scientists. In the last 10 years, staff scientists at the Center have hosted delegations representing over 10 countries from Asia and Europe. Additionally, Hamden scientists have visited and worked with scientists at forest research institutes and universities from 15 countries on 4 continents. Cooperative working agreements have been established with several foreign research laboratories—the Forest Pest Management Institute (Canada); the International Institute for Biological Control (Great Britain); at CSIRO (the Commonwealth Scientific and Industrial Research Organization of Australia); the Institut National de la Recherche Agronomique (France); and the national forest research institutes of Bulgaria, Lithuania, Russia, and the Slovak Republic.

Forest Service's research organization. Other important partners come from academia, foreign governments and research institutions, and other research organizations everywhere.

Forest health (as defined by the Forest Health Monitoring Program) denotes forest ecosystem resilience and productivity relative to a set of values, needs, and expectations. This definition emphasizes that healthy forests are those that are able to supply desired goods and services on a sustained basis. Indeed some research at the Center must be directed at protecting and maintaining healthy forests to fulfill these management objectives. **Finding and improving alternatives for managing diseases and insects will continue to be part of the Center's research focus.**

Forest ecosystems are considered healthy when plant and animal production processes are sufficiently balanced with decomposition processes to ensure that the ecosystem is sustained. Conversely, ecosystems are considered unhealthy when these primary processes of production and decay are significantly imbalanced. The health of a forest ecosystem is determined by the condition of all of the forests or stands it encompasses, and the degree of health among the components may vary depending on their stage of development and differential response to disturbance. Disturbance caused by diseases and insects, however, must also be considered within the context of normal ecosystem dynamics. **Determining and understanding the roles of microorganisms and insects in influencing ecosystem characteristics, health, and processes will become the major focus of the Center's research on these organisms.**

Diseases (both biotic and abiotic) and insects, both individually and together, play major roles in forest ecosystem dynamics, not only as pests and agents of disturbance but also as beneficial agents in the natural processes of forest succession and sustainability. **Scientists at the Center will work to determine and understand the role of diseases and insects as indicators of change, causes of change, or rejuvenators of forest health.**

Specific pests may have differential roles in forest health depending on age and species diversity within an ecosystem and whether disease organisms or insects are native or exotic to the system. Nowhere are these roles more complex than in the northeastern United States, where mosaics of diverse ecosystems exist in forests of diverse ownerships (private, municipal, state, and federal) subjected to intense multiple and often conflicting usage. These forested ecosystems are exposed to a myriad of biotic and abiotic disturbances that sometimes alter existing ecosystem conditions and processes and effect major change. Human activities, both direct and indirect, are responsible most often for upsetting the balance between production and consumption resulting in major perturbations to these ecosystems. Historically, forests in the northeastern United States have been "entry ports" for exotic organisms, and expansion of world trade will in all likelihood increase their appearance on our shores. **Research at the Center will work to determine if disturbances caused by exotic organisms have greater biological effect and potential socioeconomic impact than disturbances caused by native organisms.**

forest health research will assure a future for scenes like this

People Outreach

The 1990 National Environmental Education Act recognized the need to increase public understanding of the natural environment and to develop and advance natural resource conservation education and training. Outreach education programs at the Hamden Center have focused on increasing awareness, knowledge, and appreciation of natural resources. These efforts include

establishing partnerships to reclaim inner-city parks

- **Providing university and college students with hands-on experience in their chosen career fields and the chance for employment after completion of their academic programs.** High school and college student interns are an important part of the scene at Hamden during the summer field season. Post-docs as well as masters and PhD candidates work with Center scientists as research associates.
- **Multicultural participation in exploration of natural systems.** Scientists at the Center in partnership with The Natural Guard sponsor field trips for New Haven elementary school students. In partnership with the Urban Resource Initiative of Yale University, they are working to develop experiential environmental education programs for urban centers.
- **Training teachers in field and laboratory techniques.** Local high school teachers have worked in the insect-rearing facility and laboratories to learn how to use insects in the classroom to teach biology. Researchers are also helping to teach high school students about entomology and forest pathology.
- **Partnerships in natural resource conservation education.** The Center joins the USDA Soil and Water Conservation Districts in Connecticut in participating in the state-wide high school Envirothon Program. It also is involved in developing Connecticut's Natural Resource Conservation Education Strategic Plan.
- **Developing natural resource education materials.** Center researchers have participated in the development of Project Learning Tree's high school Forest Ecology Module, and in implementing the module at teacher workshops.
- **Developing student/teacher awareness of Forest Service activities.** The Center hosts visits and tours and discussions of on-going research with laboratory personnel.

Increasing public understanding of natural resources has focused on providing information on specific insect and disease problems. Scientists at the Center help the public by

- **Providing information to municipalities, non-profit groups, and the business community.** Center researchers speak at open forums on the biology, behavior, and impacts of forest insects and diseases and otherwise provide information so that public interest groups can participate in making pest management decisions.
- **Assisting the general public in identifying and mitigating plant, insect, and disease problems.** Individuals often bring insects and/or injured or diseased plants to the laboratory for identification and assistance in solving a pest/disease problem.
- **Providing display materials for fairs and libraries to educate the general public about the Center and how its scientists can assist them.**

THE FUTURE RESEARCH FOCUS OF SCIENTISTS AT THE CENTER FOR FOREST HEALTH RESEARCH AT HAMDEN WILL BE UNDERSTANDING AND PERPETUATING FOREST HEALTH AND ECOSYSTEM SUSTAINABILITY.

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